United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Note
PNW-RN-459

Influence of Overstory on Snow Depth and Density in Hemlock-Spruce Stands: Implications for Management of Deer Habitat in Southeastern Alaska

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Abstract

Snow depth and density were measured in 33 stands of western hemlock-Sitka spruce (*Tsuga heterophylla* [Raf.] Sarg.-*Picea sitchensis* [Bong.] Carr.) over a 3-year period. The stands, near Juneau, Alaska, provided broad ranges of species composition, age, overstory canopy coverage, tree density, and wood volume. Stepwise multiple regression analyses indicated that both overstory canopy coverage and gross wood volume were negatively related to snow depth in the forest, which was expressed as a proportion of the depth in a nearby open area. Multiple regression equations accounted for 53-79 percent of the variance in snow depth, but relationships were not consistent from one sampling period to another. Density of snow under the forest canopy, expressed as a proportion of the density of snow in the open, was less influenced by forest overstory than was snow depth. Regression equations accounted for 18-70 percent of the variance in snow density but, as with snow depth, were inconsistent from one sampling period to another. The following criteria are suggested in selecting stands for winter range for deer where snow accumulation is a problem: (1) topographic setting; (2) overstory canopy coverage at least 95 percent, as measured with a spherical densiometer; (3) timber volume class at least 20,000 board feet per acre, net volume; and (4) an understory of relatively abundant, high-quality forage.

Keywords: Wildlife habitat management, deer, winter range, overstory layer, southeastern Alaska, Alaska (southeastern), deer, *Odocoileus hemionus sitkensis*.

Introduction

Forest overstories influence snowpacks by intercepting snow and modifying the radiation environment (Hoover and Leaf 1967, Miller 1964). As a result, snow accumulates in response to overstory structure (Cline and others 1977, Ffolliot and Thorud 1972, Fitzharris 1975, Golding and Harlan 1972, Harestad and Bunnell 1981). Most studies of the influence of forest overstories on snowpacks have focused on the hydrologic aspects of snow-water equivalent and have been conducted in areas of deep snow. Generally, overstory canopy coverage is a good predictor of the effects of coniferous forests on snow-water equivalent (Harestad and Bunnell 1981).

Much less information is available on the influence of forests on snow depth and density, especially in areas of shallow or transient snow. For many ecological applications, snow depth and density are more important than snow-water equivalent. Snow is an important factor affecting the movement and energy requirements of animals. Energy expended by

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deer to move in snow is a function of both snow depth and density but not snow-water equivalent (Parker and others 1984). Snow also buries forage and makes it unavailable to deer. The combined effect of increasing costs of locomotion and decreasing availability of food make snow a major determinant of habitat quality for black-tailed deer (*Odocoileus hemionus columbianus* and *O. h. sitkensis*) (Hanley 1984, Harestad and others 1982).

The objective of this study was to determine relationships between variables of western hemlock-Sitka spruce (*Tsuga heterophylla* [Raf.] Sarg.-*Picea sitchensis* [Bong.] Carr.) overstory and snow depth and density in the low-elevation, transient-snow zone of southeastern Alaska. We sought to develop predictive equations useful for comparing the effects of any given forest stand with those of any other.

Methods

Snow depth and density were measured for 3 years in 33 stands near Juneau, Alaska. Overstory in each stand was measured once, and the snow in each stand was measured on five different occasions (sampling periods). Stands were selected to provide a broad range of species composition (exclusively spruce to nearly exclusively hemlock), age (40 to more than 400 years), canopy coverage (9.1-100 percent), tree density (16-2,803 trees/ha), and gross wood volume (6-1338 m^3/ha). All stands were on level or nearly level ground (slope gradients less than 10 percent) and were close to a large open (nonforest) area where snow could be measured at distances greater than two tree-heights from the forest. All stands were low elevation (less than 100 m), unmanaged hemlock-spruce forest. Snow measurements were made when a wide range of depths and densities could be obtained.

Each stand was selected for homogeneity. All measuring and sampling were done within circular plots 30-70 m in diameter. The sizes of the plots varied in proportion to the variation in basal area and canopy coverage of the stand. Basal area and canopy coverage were estimated at the center of the circle and at 5-m intervals along transect lines running in each of the four cardinal directions from the center. Basal area was estimated with a relaskop and the variable plot method (Dilworth 1977). Overstory canopy coverage was estimated with a spherical densiometer (Lemmon 1956). The number of sample points required to obtain a standard error less than or equal to 10 percent of the mean was calculated for both basal area and canopy coverage. The larger of these two numbers determined the size of the circular plot to be sampled.

The diameter at breast height (d.b.h) and total height of each tree with a d.b.h. greater than 2 cm was estimated with a relaskop. The species of each tree was identified, and signs of wood defect were noted. These measurements provided the following data for each forest stand: tree density (trees per hectare), percentage of spruce (by density), mean d.b.h., coefficient of variation of d.b.h., mean tree height, coefficient of variation of tree height, gross wood volume (cubic meters per hectare), net wood volume, basal area (square meters per hectare), and mean overstory canopy coverage (percentage). Additionally, each stand was categorized as even-aged or uneven-aged.

Snow measurements were made at 3-m intervals within the circular plot in each stand (a 5-m buffer zone was left at the edge of the plot) and in the nearby open area. Fifty measurements of snow depth were made in each stand and open area at each sampling. Snow density was measured with a standard U.S. Soil Conservation Service snow measuring tube. The number of samples, which varied in proportion to the variation in the measurements, was sufficient to obtain a standard error less than or equal to 10 percent

of the mean. All stands were sampled as close to one another as possible—within 3 to 6 days. Snow data were obtained from February 1982 through January 1984. Only 27 stands were sampled in 1982; 6 more were added for the 1983 samples; and 4 were deleted from the 1984 sample because of disturbance to the overstory.

Data were analyzed with the SPSS statistical programs (Nie and others 1975). A correlation matrix for all variables was calculated, and scatterplots of each variable against snow depth and against snow density were examined separately for each snow sampling period and for all periods combined. Distinctly nonlinear relationships were transformed. Four overstory variables were selected for further analysis on the basis of their having an interpretable functional relation to snowpack and having minimum intercorrelations among themselves. These variables, along with mean snow depth or density in the open area, were treated as independent variables in stepwise regression analyses with proportional depth (mean snow depth in the forest divided by mean snow depth in the open area) and proportional density as dependent variables. Data from each snow measuring period were analyzed separately and then were combined into one analysis.

Results and Discussion

Mean snow depths in the open ranged from 23 to 94 cm (table 1). Mean snow densities in the open ranged from 0.09 to 0.18 g/ cm^3. Snow in the forest stands was, on average, only 62 percent as deep as that in the open but was of very similar density. Mean snow depths in the open areas and the forest stands were most similar under the deepest conditions and least similar under medium to low depths. Disparities between densities in open areas and forest stands were important only under the wettest, densest conditions, when density was greater in the forest than the open.

Table 1—Summary of mean snow depths and densities from measurements in forest stands and open areas on 5 sampling dates

		Depth		Density		
Sampling period	Date	Open areas	Forest stands	Open areas	Forest stands	Number of stands
		——cm——		——g/cm^3——		
1	21-26 Feb. 1982	94	71	0.12	0.12	27
2	14-19 Jan. 1983	49	31	.12	.12	33
3	14-18 Feb. 1983	57	26	.11	.10	33
4	21-26 Dec. 1983	23	11	.09	.09	33
5	26-28 Jan. 1984	59	37	.18	.23	29

We selected overstory canopy coverage, gross wood volume, percentage of spruce, forest type (even-aged versus uneven-aged), and mean snow depth in the open as independent variables in the multiple regression analysis for predicting proportional depth of snow in the forest. We reasoned that overstory canopy coverage provided our best measure of the horizontal distribution of forest canopy; gross wood volume provided our best measure of overstory mass; percentage of spruce accounted for differences in species composition of the stand; forest type accounted for potential differences in the amount of snow intercepted by old-growth stands compared to even-aged stands; and mean snow depth in the open accounted for differences in total amount of snow. Only the relation between overstory canopy coverage and proportional depth of snow was distinctly nonlinear. Canopy coverage was transformed with an exponential transformation: $e^{x \div 10}$.

Table 2—Results of stepwise multiple regression analysis with proportional depth (depth of snow in the forest divided by depth of snow in the open) as the dependent variable

		Regression coefficients of independent variables[1]				
Sampling period	Constant	Depth in open[2]	Canopy coverage[3]	Wood volume[4]	Forest type[5]	R^2
1	1.079	[6]—	-2.284 (0.70)	—	—	0.70
2	.678	0.168 (.16)	-1.313 (.11)	-3.415 (.44)	—	.71
3	.669	—	-2.990 (.45)	—	0.178 (.08)	.53
4	1.115	—	-3.188 (.68)	-3.190 (.05)	—	.74
5	2.068	-.447 (.13)	-2.842 (.66)	—	—	.79
1-5[7]	0.809	.094 (.11)	-2.126 (.48)	-2.192 (.04)	—	.63

[1]Values listed for independent variables are their regression coefficient and their contribution to the multiple R^2 (in parentheses). Percentage of spruce also was included in the analysis but was never significant enough to enter the multiple regression equations (see footnote 6).
[2]Depth in open area (centimeters), times 10^{-1}.
[3]Overstory canopy coverage (percentage) transformed by $e^{x \div 10}$, times 10^{-5}.
[4]Gross wood volume (cubic meters per hectare), times 10^{-4}.
[5]Forest type = 1 for uneven- aged; 2 for even- aged.
[6]Dash indicates that the variable accounted for an insignificant amount of variation and was not included in the regression equation (that is, F to enter was <0.01 and/or tolerance was <0.001).
[7]All data combined.

Stepwise multiple regression analyses indicated (1) that of the five independent variables, only canopy coverage consistently accounted for a significant proportion of the variance in proportional depth of snow; (2) that gross wood volume was the next best predictor of proportional depth; (3) that the species composition and even-aged versus uneven-aged structure of the forest were irrelevant; and (4) that although 53 to 79 percent of the total variance in proportional depth was accounted for with only one to three independent variables, the equations were not consistent from one sampling period to another (table 2). The most consistent pattern was that proportional depth was negatively correlated with both overstory canopy coverage and (to a lesser degree) gross wood volume. The effect of canopy coverage was pronounced only at high levels of coverage (at least 95 percent, fig. 1), however; the effect of wood volume was most pronounced at low levels of volume (less than 400 m^3/ha, fig. 2).

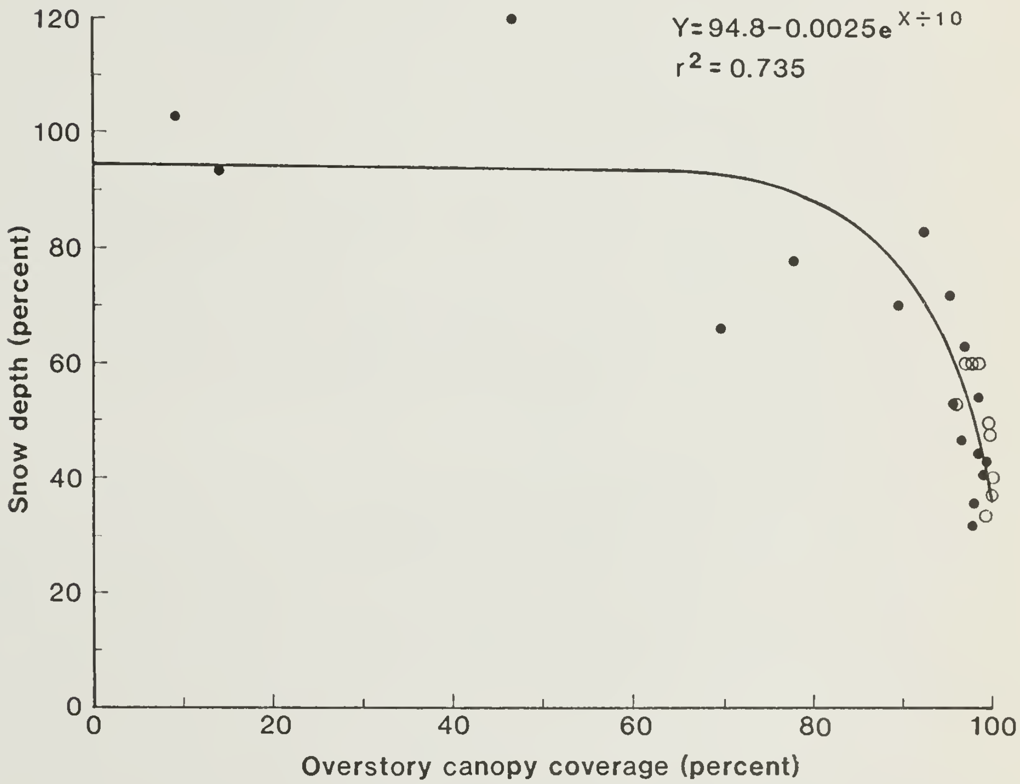

Figure 1—Mean snow depth in the forest (as a percentage of depth in the open) as a function of overstory canopy coverage. Each point is the mean of five sampling periods. Only stands that were measured in all five periods are included. Solid circles represent uneven-aged stands; open circles represent even-aged stands.

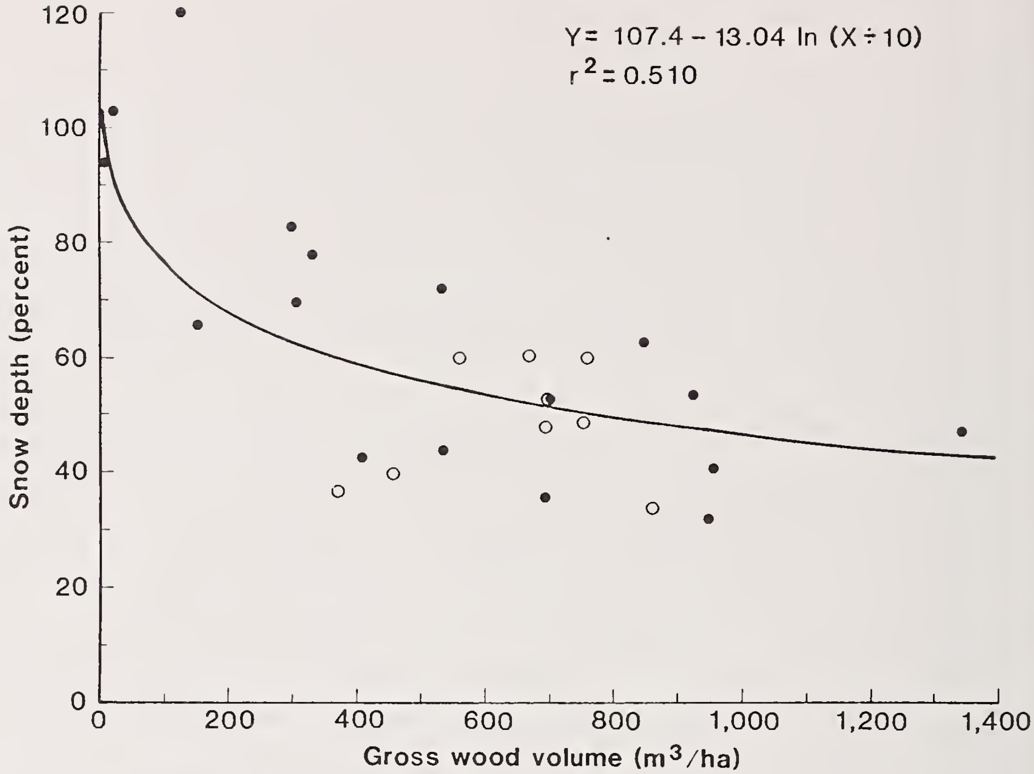

Figure 2—Mean snow depth in the forest (as a percentage of depth in the open) as a function of gross wood volume. Each point is the mean of five sampling periods. Only stands that were measured in all five periods are included. Solid circles represent uneven-aged stands; open circles represent even-aged stands.

The relations between overstory variables and proportional density of the snowpack were much less clear than those for proportional depth of snow. Of all the overstory variables, only tree density was significantly correlated (negatively) with proportional density of the snow. Multiple regression analyses with snow density in the open, overstory canopy coverage, and tree density as independent variables indicated that 18-70 percent of the variance in proportional density was accounted for by snow density in the open area and by tree density (table 3). Snow density in the open area was the most important variable for predicting proportional density of the snow. As with proportional depth, though, the equations were not consistent from one sampling period to another. Although proportional density was negatively correlated with density in the open for any one sampling period, it was positively correlated in the combined data set. This reflected the small differences in snow density encountered between stands during any one sampling period relative to the large difference in snow density encountered in period 5 versus all other periods (table 1).

These results indicated that in western hemlock-Sitka spruce stands varying across broad ranges of species composition, age, canopy coverage, tree density, and wood volume, overstory canopy structure exerts a significant influence on snow depth but much less influence on snow density. Overstory canopy coverage and gross wood volume are the best predictors of the influence on snow depth, but the relations change with snow conditions. Forest overstory, for example, may exert a greater or lesser

influence depending on whether the snow falls during cold, windy conditions or warm, still conditions, or whether it falls in one intense storm or in several intermittent storms. Although our relations account for a reasonable amount of variation over broad ranges of forest structure, the data are much too variable to be satisfactory over shorter ranges (that is, in comparisons of fairly similar stands). This problem was apparent when we made the snow measurements. We could always be certain the snow would be deepest in the most open stands and shallowest in the most closed stands, but intermediate stands varied in their relative depths from one sampling period to another. Our study focused on the effects of stand and tree stem characteristics on snowpack. Greater resolution would require focusing on individual trees and their crown characteristics and on weather conditions.

Table 3—Results of stepwise multiple regression analysis with proportional density (density of snow in the forest divided by density of snow in the open) as the dependent variable

		Regression coefficients of independent variables2/		
Sampling period1/	Constant	Density in open3/	Tree density4/	R^2
1	2.817	-15.070 (.47)	5/—	0.47
2	.906	—	1.112 (.18)	.18
3	1.253	-4.274 (.30)	1.139 (.10)	.41
5	1.881	-4.178 (.56)	2.018 (.14)	.70
6/1-5	.801	.908 (.98)	1.411 (.01)	.99

1/Snow depths and densities were too low to measure density accurately in period 4.
2/Values listed for independent variables are their regression coefficient and their contribution to the multiple R^2 (in parentheses). Overstory canopy coverage also was included in the analysis but was never significant enough to enter the multiple regression equations (see footnote 5).
3/Density in open area (grams per cubic centimeter).
4/Number of trees per hectare, times 10^{4}.
5/Dash indicates that the variable accounted for an insignificant amount of variation and was not included in the regression equation (that is, F to enter was <0.01 and/or tolerance was <0.001).
6/All data combined, except period 4.

Implications for Research

The transient-snow zone poses technical problems that differ from those of areas with deep and persistent snowpacks. We encountered several major problems while conducting this study. Because our stands were relatively large and widely dispersed, we needed 3 to 6 days to sample them during the short days of winter. Snow depths can change greatly in 3 to 6 days in transient-snow zones (Berris 1984). Although each of our plots was paired with an adjacent open area, the differences from day 1 through day 6 undoubtedly contributed to the variation in our data. This should be true especially for shallow snow, where a given change in depth is proportionally greater than it is for deep snow. Shallow snow also created problems in measuring density with the Soil Conservation Service snow tube, a device designed for measuring deep snow. The difficulties of accurately measuring density compounded the problem of sampling stands rapidly. And density, like snow depth, can change rapidly, especially if rainfall is a factor (Berris 1984).

Our results indicated that overstory canopy coverage was potentially the most useful factor for predicting the influence of overstory on snow. This is consistent with the results of most studies of forest influences on snowpacks (reviewed by Bunnell and others 1985, Harestad and Bunnell 1981). Of the variables we considered, however, overstory canopy coverage was the most difficult to measure. Indeed, it cannot be measured directly but must be estimated. We used a spherical densiometer because it has high precision (Vales and Bunnell 1985). Its accuracy is low, however, because it projects a wide angle of view toward the canopy and, therefore, overestimates canopy coverage directly overhead (vertical) (Vales and Bunnell 1985). The result was that 23 of our 33 stands had canopy coverage values greater than 95 percent. These also were the stands that had a pronounced effect on snowpack.

We encountered a high degree of variability between stands and between sampling periods. Part of the variability may be attributed to the problems above, but most is more likely because of vagaries of weather and their effect on the processes controlling snow interception, sublimation, and melt. Weather conditions during a snowstorm (including air temperature, wind speed, wind turbulence, rate of snowfall, duration of snowfall, and amount of snowfall) and following a storm (including air temperature, precipitation, solar insolation, wind speed, and vapor pressure deficit) play major roles in affecting forest influences on snowpacks (Bunnell and others 1985). Additionally, tree characteristics such as branch size and load capacity, leaf or needle configuration, leaf area, crown architecture, and spacing between neighboring trees are very important (Bunnell and others 1985). These variables were essentially unaccounted for in our analysis. High precision in predicting the effects of forests on snowpacks undoubtedly requires modeling of processes that control snow interception, sublimation, and melt. Regressions based on stand attributes from forest inventory data will undoubtedly yield low levels of precision, especially over time (variety of snowfall events). This is most likely in the transient-snow zone, where cycles of snow deposition and melting alternate throughout the winter.

Implications for Management of Deer Habitat

Our results indicated that over very broad ranges of canopy coverage and wood volume these two variables can serve as useful indices of the effects of forest overstories on snowpacks. In general, open-canopied stands accumulate and retain more snow than do closed-canopied stands. But over narrow ranges of canopy coverage and wood volume, these two variables are poor predictors of the effect of overstory on snowpack.

Our results indicated, for example, that canopy coverage exerts essentially no influence on snowpack at values less than about 60 percent coverage, a moderate effect at values between 60 and 95 percent, and a substantial but highly variable effect at values greater than 95 percent (measured with the spherical densiometer). Similarly, our results indicated that stands with less than 100 m^3/ha gross wood volume (about 1,200 net board feet per acre) have essentially no effect on snowpack, stands with 100-400 m^3/ha gross wood volume (about 1,200-17,000 net board feet per acre) have a moderate effect, and stands with more than 400 m^3/ha gross wood volume have a substantial but highly variable effect on snowpack. Most questions about commercial-sized stands are for those with more than 20,000 board feet per acre net volume (about 550 m^3/ha gross volume). Therefore, within most of the commercial-sized stands, neither canopy coverage nor wood volume are very useful predictors of the effects of forest overstory on snowpack.

These results are similar to the patterns observed by Kirchhoff and Schoen (1985), who measured snowpack and overstory variables in a study area near Juneau, Alaska. Their method of measuring overstory canopy coverage differed from ours and yielded a more linear relation, but the implications for both canopy coverage and wood volume are qualitatively the same as those above.

Our data also indicated no differences related to the species composition or to whether stands were even-aged or uneven-aged. These might be important variables at a finer scale of resolution, but given the variation we encountered, they were unimportant.

Within commercial-sized stands (at least 20,000 board feet per acre, net volume), the most important factors affecting snowpack are apparently related to weather rather than to forest overstory. This was particularly evident in the relative differences we encountered between stands on different dates: relative depths differed greatly, yet the overstories remained the same. Furthermore, as total snowfall increases, forest overstories tend to have a decreasing influence on snowpack (Harestad and Bunnell 1981). Weather, of course, is strongly influenced by climate and topography. Snow is most likely to occur and accumulate in cold climates, at high elevations, on northern exposures, on level ground, on shaded slopes, in valley bottoms subjected to cold-air drainage, at heads of narrow inlets, and in areas distant from the relatively warm (in winter) salt water of the Alexander Archipelago. For commercial-sized stands, topography is probably a better indicator of snowpack than is forest overstory.

The following criteria should be helpful in selecting stands for winter range for deer where snow accumulation is a problem: (1) topographic setting (for example, unshaded, low-elevation, moderate to steep, southerly slopes on a point or peninsula projecting into salt water); (2) overstory canopy coverage at least 95 percent, as measured with a spherical densiometer; (3) timber volume class of at least 20,000 board feet per acre, net volume; and (4) an understory of relatively abundant, high-quality forage (for example, a *Vaccinium* spp./*Cornus canadensis-Rubus pedatus* understory) (Hanley and McKendrick 1985). The effects of snow on deer are greater for food (energy intake) than for locomotion (energy expenditure) at the depths usually encountered in the transient-snow zone (less than 50 cm) (Wickstrom and others 1984). At depths greater than 50-60 cm (brisket height), however, energy costs for locomotion become especially great as deer are forced to jump while traveling through the snow (Parker and others 1984). Maximum interception of snow may be expected for stands with high levels of both overstory canopy coverage and wood volume. Such stands could provide important refuge for deer when snow is deep, but if the understory is sparse, few deer could be supported for long.

Acknowledgments

We thank G.G. Fisch for assistance with the fieldwork and F.L. Bunnell, A.S. Harestad, R.D. Harr, and T.A. Max for their helpful reviews of an earlier draft of the manuscript.

English Equivalents

1 centimeter (cm) = 0.39 inch
1 cubic centimeter (cm^3) = 0.06 cubic inch
1 meter (m) = 39.4 inches
1 square meter (m^2) = 10.76 square feet
1 cubic meter (m^3) = 35.31 cubic feet
1 hectare (ha) = 2.47 acres
1 gram (g) = 0.04 ounce

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Appendix

Correlation Matrix of Overstory Variables

Variables	Percentage of spruce	Mean d.b.h.	Mean height	Canopy coverage	Basal area	Gross wood volume
Tree density	0.266	-0.653	-0.157	0.386	0.359	-0.001
Percentage spruce		-.241	-.027	.231	.197	-.018
Mean d.b.h.			.728	.188	.151	.450
Mean height				.649	.572	.657
Canopy coverage					.773	.644
Basal area						.738

July 1987

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